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Research Review

Energy requirements of military personnel

William J. Tharion[a,*], Harris R. Lieberman[a], Scott J. Montain[a], Andrew J. Young[a], Carol J. Baker-Fulco[a], James P. DeLany[b], Reed W. Hoyt[a]

[a]*Military Nutrition Division, US Army Research Institute of Environmental Medicine, Kansas Street, Natick, MA 0176-5007, USA*
[b]*Pennington Biomedical Research Center, Baton Rouge, LA 70808-4124, USA*

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Abstract

Energy requirements of military personnel (Soldiers, Sailors, Airmen, and Marines) have been measured in garrison and in field training under a variety of climatic conditions. Group mean total energy expenditures for 424 male military personnel from various units engaged in diverse missions ranged from 13.0 to 29.8 MJ (3109–7131 kcal) per day. The overall mean was 19.3 ± 2.7 MJ (mean ± SD) (4610 ± 650 kcal) per day measured over an average of 12.2 days (range 2.25–69 days). For the 77 female military personnel studied, mean total energy expenditures for individual experimental groups ranged from 9.8 to 23.4 MJ (2332–5597 kcal) per day, with an overall mean of 11.9 ± 2.6 MJ (2850 ± 620 kcal) per day, measured over an average of 8.8 days (range 2.25–14 days). Women, presumably due to their lower lean body mass, resting metabolic rate, and absolute work rates, had lower total energy expenditures. Combat training produced higher energy requirements than non-combat training or support activities. Compared to temperate conditions, total energy expenditures did not appear to be influenced by hot weather, but tended to be higher in the cold or high altitude conditions.

Keywords: Doubly labeled water; Environment; Exercise; Military feeding; Military training; Nutrition; Soldiers

Introduction

Commanders and logisticians are responsible for meeting the energy and other nutritional needs of their military personnel (Soldiers, Sailors, Airmen, and Marines). However, the military population is heterogeneous, varying physically and performing vastly different occupational tasks. Some military personnel have relatively sedentary jobs, while others perform near-continuous physical work. Military feeding programs need to meet these widely varying total energy requirements.

The consequences of providing a nutritionally inadequate diet are well documented. Dietary insufficiency can depress immune function (Keusch, 2003), prolong recovery from illness and injury (Brown, 1994; Tucker, 1997) and compromise physical performance (Hultman, 1967; Jeukenendrup, Brouns, Wagenmakers, & Saris, 1997; Johnson, Friedl, Frykman, & Moore, 1994; Shippee et al., 1994). Accordingly, the military has developed a variety of food delivery systems intended to provide military personnel with desirable foodstuffs that meet nutritional requirements, whether in garrison or in remote field conditions exposed to environmental extremes. However, current feeding routines, that is, food and food delivery, do not always meet the nutritional needs of military personnel (Meiselman, 1995). In the field, mean intakes of groups of military personnel rarely have been greater than 12.6 MJ/day (1 MJ = 239 kcal) (Baker-Fulco, 1995). Underfeeding can also be a concern in garrison, as reflected by the US Army Special Operations Command requests, on behalf of the 75th Ranger Regiment and the 10th Special Forces Group, to have scientific studies performed to determine whether their foodservice operations provided the food energy needed for these physically active soldiers (reference notes 1 and 2). The issue for the Special Operations

* Corresponding author.
E-mail address: william.tharion@na.amedd.army.mil (W.J. Tharion).

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communities is do they have enough money to cover the cost of meals for their personnel, whose nutritional requirements may be different than other units. To improve the efficacy of military feeding systems, investigators have measured total energy expenditures of service members with many different jobs under a variety of environmental conditions (Appendix A). The purposes of this review are; (a) highlight advantages of the doubly labeled water method for estimating total energy expenditures, (b) to illustrate differences in total energy expenditures of various military groups, (c) discuss how military specialty or occupational task, gender, and environmental conditions impact the various military units' total daily energy requirements, and (d) provide the data to determine if certain groups of military personnel may need to be reimbursed at a higher rate for meals served based on higher energy needs of the military personnel they serve.

Measurement of energy expenditure

A scientific challenge to establishing the dietary requirements of military personnel has been the accurate assessment of energy expenditure. A classic, gold standard approach for estimating total energy expenditure has been the intake-balance method, where total energy expenditure is estimated from food intake and changes in body composition. This method requires a relatively long evaluation period and accurate determination of energy intake and change in body energy stores (Hoyt et al., 1991b).

The factorial method, another classic way to estimate total energy expenditure, involves recording the type and duration of all physical activities and calculating total energy costs using published literature values for each specific or similar activity (Ainsworth et al., 1993). However, this approach can be imprecise. For example, using anthropometric data (Gordon et al., 1989) and the formula from Cunningham (1980), the estimated metabolic rates of male US Army soldiers between the 10th and 90th percentiles ranges from 7.2 to 9.4 MJ/day. Furthermore, the energy cost of physical activity can increase metabolic rate up to 20-fold. Therefore, any error in the estimate of either intensity or duration of activity can lead to large errors in the estimation of the energy cost.

Metabolic cost can also be estimated from oxygen consumption (indirect calorimetry) or by direct calorimetry (McLean & Tobin, 1987; Montoye, Kemper, Saris, & Washburn, 1996). However, these methods require collecting expired air during the measurement period, by having volunteers either enclosed in a whole-room respirometer or tethered to a breathing apparatus for oxygen consumption data collection, and therefore are impractical for determining the energy requirements of military personnel in operational environments. In contrast, the doubly labeled water technique, using the stable isotopes of $H_2^{18}O$ and ^2H_2O as tracers, can precisely measure total energy expenditures without interfering with the test volunteers' activities.

The doubly labeled water method for measuring total energy expenditure is based on the differential elimination of hydrogen and oxygen labels (Schoeller, 1988). Since deuterium assesses whole-body water turnover, and $H_2^{18}O$ measures water turnover and CO_2 turnover, CO_2 production can be calculated from the difference in the two rates of tracer elimination. Energy expenditure can then be calculated from CO_2 production using standard conversion factors (Lusk, 1928).

The doubly labeled water method was developed to assess energy expenditure in small free-living animals (Lifson & McClintock, 1966). The use of the method in humans became practical with the improved analytical sensitivity of isotope ratio mass spectrometers and decreases in the cost of $H_2^{18}O$. The doubly labeled water method has been validated in humans against the intake-balance method, the factorial method, and indirect calorimetry (Forbes-Ewan, Morrisey, Gregg, & Waters, 1989; Roberts, 1989; Schoeller, 1988; Schoeller & Van Santen, 1982).

Since the first human field study in 1982 (Schoeller & Van Santen, 1982), the technique has been used in a diverse set of volunteers and experimental settings (Black, Coward, Cole, & Prentice, 1996). The doubly labeled water method typically involves the ingestion of a dose of doubly labeled water after a brief (usually overnight) fast, and the periodic collection of urine or saliva samples. No other demands are made of the volunteers. The doubly labeled water method is especially useful when measuring total energy expenditures of military personnel operating in harsh or restricted locations.

Energy expenditures of military personnel generally exceed those of civilians

Most military energy expenditure studies have examined dismounted soldiers deployed in field training exercises that typically involve 3–10 days of continuous training. During this training, operational rations are usually consumed and military personnel sleep in tents or in the open without shelter. In general, when deployed for combat or combat support missions or training in the field, military personnel are more physically active than when training in garrison.

Garrison training typically involves military personnel training during the day on or around a military installation, and returning to eat in a dining facility and sleep in dormitory-type rooms.

Among studies in which energy requirements of military personnel were measured, energy requirements ranged from a low of 9.8 MJ/day for female administrative personnel (Baker-Fulco et al., 2002) to a high of 29.8 MJ/day for male Marines engaged in mountain warfare training (Hoyt et al., 1991b). The total energy expenditure measurement of all

male military personnel reported ($N=424$), averaged 19.3 ± 2.7 MJ/day across all activities, military occupational specialties, and environments. The mean measurement period was 12.2 days (range 2.25–69 days). These values are approximately 38% greater than the mean total energy expenditure of 92 civilian men aged 18–39 yr (similar in age to the military personnel summarized), who averaged 14.0 ± 3.1 MJ/day (Black et al., 1996). Total energy expenditures of military women ($N=77$; 11.9 ± 2.6 MJ/day, mean measurement period, 8.8 days (range 2.25–14 days) were about 17% greater than their civilian counterparts. Total energy expenditures of 165 civilian women, aged 18–39 yr, averaged 10.2 ± 4.4 MJ/day (Black et al., 1996).

Any comparison of civilian and military personnel energy expenditures needs to account for the fact that many military studies are of individuals participating in limited duration field exercises. As in certain athletic events, such as ultramarathons or the Tour de France cycling race, military field exercises often result in higher energy expenditures than in the general civilian population because of prolonged workdays and the physical nature of the activities (see Appendix A for a complete list of total daily energy expenditures of military personnel in different environments performing various tasks). Civilian personnel engaged in arduous physical labor such as firefighters, can likewise expect to have higher levels of energy expenditures (e.g., 17.5 MJ/day) (Ruby et al., 2002). When both age and job-type are considered it appears that the total daily energy expenditures of military and civilian personnel will probably be similar.

The metastudy of Black et al. (1996) reported that male civilians, 18–39 yr of age had a mean energy expenditure of 14.0 MJ/day. Male military personnel who had energy expenditures less than or equal to 14.0 MJ/day included Marine administrative staff and supervisors on a construction mission (13.0 MJ/day) (Tharion et al., 2000a), Australian sailors on shore duty (13.8 MJ/day) (Forbes-Ewan, Morrissey, & Gregg, 1990), US astronauts during a Space Shuttle mission (13.9 MJ/day) (Stein et al., 1999), and Zimbabwean support soldiers (14.0 MJ/day) (Mudambo, Scrimgeour, & Rennie, 1997). These studies indicate that some military personnel have energy expenditures comparable to civilians, even though most military personnel exceed these levels for a number of reasons described below.

Energy expenditures of combat units are greater than combat support units

Energy expenditures of members of combat units and soldiers who support them (combat support groups) were determined and compared in three different studies (Table 1). Special Forces soldiers training in garrison expended approximately 19% more energy than their support soldiers. However, Special Forces soldiers often have a larger body mass than other soldiers, and because of this, the difference was only 5% when total energy expenditure was expressed per kilogram body weight (Bovill et al., 2002). The activities of the Special Forces soldiers consisted of foreign language practice, load carriage, rock and mountain climbing, combat training, and small weapons handling, while for support soldiers it consisted of standard physical training, assembling equipment for use by the Special Forces, driving vehicles to training sites, and office work.

Combat soldiers were found to expend significantly more energy than combat support soldiers in two other studies, even when energy expenditure measurements were

Table 1
Total energy expenditures per day of combat support soldiers and combat soldiers under similar conditions

Population (reference)	Task	N	Duration (days)	Total energy expenditures[a] (MJ/day (kcal/day))	Total energy expenditures/kg body mass[a] ($MJ \cdot kg^{-1} \cdot day^{-1}$ ($kcal \cdot kg^{-1} \cdot day^{-1}$))
US Army soldiers training in garrison (Bovill et al., 2002)	Support activities	10	9	14.4 ± 2.9 (3445)	0.20 (47.1)
US Special Forces soldiers training in garrison (Bovill et al., 2002)	Combat training	10	9	17.2 ± 3.1 (4099)	0.21 (49.3)
Zimbabwean combat support soldiers (Mudambo et al., 1997)	Support activities	4	12	14.0 ± 1.0 (3346)	0.21 (50.4)
Zimbabwean combat commando soldiers (Mudambo et al., 1997)	Combat training	8	12	23.0 ± 4.1 (5497)	0.36 (85.4)
US Army soldiers transportation unit (Tharion et al., 1998)	Support activities	3	16	14.9 ± 3.1 (3568)	0.20 (46.7)
US Army Rangers training in garrison (Tharion et al., 1998)	Combat and physical training	8	8	18.9 ± 2.6 (4518)	0.26 (61.3)
US Army Rangers field training (Tharion et al., 1998)	Combat training	8	8	21.7 ± 2.8 (5185)	0.29 (70.4)

[a] Total energy expenditures in MJ are expressed as mean $\pm$ SD and mean (kcal).

normalized to body mass. Zimbabwean combat soldiers expended 64% more energy (71% more on a per kilogram body weight basis) than did their support unit soldiers (Mudambo et al., 1997). In that study, soldiers in combat training carried approximately 30 kg of military equipment (boots, helmets, rifles, specialized military clothing, and backpacks) and participated in running exercises, calisthenics, assault and battle drills, obstacle tackling, patrol drills, 10-km marches and team sports (soccer and volleyball) while their support soldiers worked in the field kitchen, cleaned, and maintained the camp (Mudambo et al., 1997). In the third study, US Army Rangers expended more energy both in garrison (27%) and in the field (45%) than support soldiers assigned to a transportation company who were in garrison (Tharion, Warber, Hoyt, & DeLany, 1998). Activities for the Rangers in garrison included physical training, such as running, weight lifting, and calisthenics, and military tasks such as operating specialized equipment, weapons training, and inventorying, packing, and loading equipment. When deployed to the field, Ranger activities included squad and platoon attacks, ambush training, small arms training, and sentry and perimeter defense maneuvers. The transportation unit soldiers drove vehicles to transport personnel and equipment, and maintained their vehicles (Tharion et al., 1998).

Military training schools elicit high energy expenditures in military personnel

Total energy expenditures of soldiers participating in military training schools can be quite high. For example, total energy expenditures of personnel completing the US Air Force Combat Survival Course averaged 19.7 MJ/day (Jones et al., 1992), soldiers attending the US Army Special Forces Assessment School averaged 21.7 MJ/day (Fairbrother et al., 1995), and Marines at the US Marine Corps Infantry Officer Course, averaged 22.5 MJ/day (Hoyt et al., 2001). The US Air Force Survival Course was a 5-day course that trains aircrew members in parachuting and survival, evasion, resistance, and escape procedures. Additionally, psychological stress to simulate a prisoner of war scenario is imposed on these aircrew members (Jones et al., 1992). The Special Forces Assessment School course study was 20 days in duration and took place in a temperate environment (27 °C, 65% relative humidity). The Special Forces Assessment School course included activities such as physical fitness tests, battle marches, and long-range movements carrying backpacks, weapons, and other field equipment. Key stressors in the Special Forces Assessment School course were intense periods of physical exertion and some sleep restriction. These soldiers slept approximately 6 h a day according to activity monitor data (Fairbrother et al., 1995). In the Marine Officer course, heart rates were measured and used as an index of physical activity, with the highest rates of energy expenditure coming from frequent movements and attacks. Other physically demanding activities performed less frequently included conducting offensive military operations in urban terrain and establishing defensive positions (digging in). Less physically strenuous activities included live fire exercises and movement by helicopter. The common component among training schools leading to elevated energy expenditures is that instructors keep students physically active 16–22 h a day (Fairbrother et al., 1995; Hoyt et al., 2001; Shippee et al., 1994). The purpose of the long physically active training days is two-fold; (a) to give the students as much training in as short a period of time as possible, and (b) to impose a physical and psychological stressor upon these military personnel to prepare them for the stress of combat.

In contrast to the relatively short duration of the courses above, students enrolled in the US Army Ranger School training course train continuously for over 60 days (the longest duration of the energy expenditure studies in this review). While their total energy expenditures are lower than the other courses cited, they sustained relatively high total energy expenditures of 16.8 MJ/day (Moore et al., 1992) and 17.1 MJ/day (Shippee et al., 1994) for over 2 months. Ranger training was comprised of four phases: forest, mountain, swamp, and desert environments averaging 65 days when these studies were conducted. Now Ranger training averages 56 days with no desert phase. Repeated, periodic food restriction is one of the intentional stressors of the course. Besides food restriction and environmental stressors, other stressors imposed on the students include sleep deprivation, prolonged low intensity work, anxiety produced by harassing opposition forces, and constant performance evaluation (Shippee et al., 1994). Combat fundamentals taught during the course include; patrolling, squad recon and ambush, training in mountaineering, small boat operations, and attack, ambush, and raid drills (Shippee et al., 1994).

Impact of mission and environmental conditions

Garrison versus field

Total energy expenditures while in garrison of US Army Special Forces support soldiers were 14.4 MJ/day (Bovill et al., 2002). These total energy expenditures were similar to those of a US Army transportation unit in garrison (14.9 MJ/day) (Tharion et al., 1998). In soldiers with comparable jobs deployed to the field, total energy expenditures for medical support personnel were 17.5 MJ/day (Baker-Fulco et al., 2002), a 19% increase in energy expenditures for support-type soldiers. US Army Rangers' total energy expenditures increased from a peak of 18.8 MJ/day in garrison to 21.8 MJ/day in the field, a 15% increase (Tharion et al., 1998).

Total energy expenditures of US Army Special Forces soldiers in garrison were 17.2 MJ/day (Bovill et al., 2002), but only 14.5 MJ/day (DeLany, Schoeller, Hoyt, Askew, & Sharp, 1989) and 17.8 MJ/day (Hoyt et al., 1994) in the field. This lack of increase in DeLany et al. (1989) study may partly be explained by the length of the exercise (28 days) which was relatively long compared to the other studies cited above (6 days, Hoyt et al., 1994; 8 days, Tharion et al., 1998; 9 days, Bovill et al., 2002; and 11 days Baker-Fulco et al., 2002). The other possibility for the relatively lower total energy expenditure in DeLany et al. (1989) field study may be because it was part of a restricted ration study where soldiers were underfed and had restricted training opportunities (Askew et al., 1987). Furthermore, in DeLany et al. (1989) study, US Special Forces soldiers were training in a temperate, sea level, moderately hilly, forested area. The Special Forces training in garrison was performed in and around Ft Carson, Colorado with much of the training occurring in mountainous terrain and at moderate levels of altitude in the Rocky Mountains. High altitude increases total energy expenditure for a number of reasons discussed later in this review.

In addition to an abundance of ambulatory activities and carrying heavy loads, an important factor increasing energy requirements during field training are long workdays. Military workdays in the field often exceed 16 h of activity, verified by ambulatory monitoring using wrist-worn activity monitors or foot pedometers (Hoyt et al., 1991b, 1994; Shippee et al., 1994; Tharion et al., 1997a; Tharion, Yokota, Buller, DeLany, & Hoyt, 2002). In contrast, most soldiers in garrison typically train less than 12 h per day and do not train on weekends (Bovill et al., 2002).

Relationship between energy intake and energy expenditure

During deployments and field training, energy expenditures are high with energy intakes unable to match expenditures. However, no systematic relationship was evident between total energy intake and total energy expenditure ($r=0.09$) (Fig. 1). Military training schools often use food restriction as an intentional stressor perhaps confounding the findings. However, if the five studies of military school courses with energy intake and expenditure data are excluded, the correlation between total energy intake and total energy expenditure remained poor ($r=0.31$). Military personnel usually consume insufficient energy, whether they are provided an adequate amount or not. For example, in the US Air Force Survival Course, total energy expenditures were 19.7 MJ/day for the 5-day course. Yet, these students consumed only 60% (3.2 MJ/day) of the meager 5.3 MJ/day provided. An energy deficit of 16.5 MJ/day was calculated from food energy intake and changes in body fuel stores (Jones et al., 1992). In the Special Forces Assessment School course, food restriction was not an intentional stressor, as students received a food provision of approximately 16.3 MJ/day.

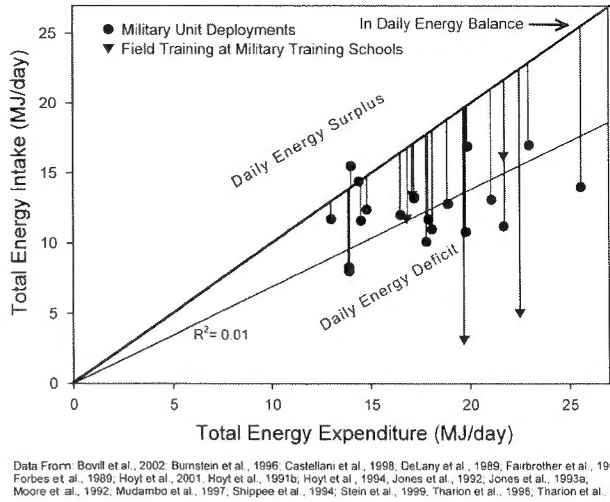

Fig. 1. Total energy expenditure as a function of total energy intake.

Average energy intake was 15.9 MJ/day with an estimated energy deficit of 5.9 MJ/day for 20 days (Fairbrother et al., 1995).

It might be expected that students in military training courses would have energy expenditures unrelated to intakes since course objectives and food provisions are dictated by the course requirements. However, whether during a training school course or during unit deployments, most military personnel given the choice between accomplishing a mission and eating a meal will forgo eating (Kramer, 1995). While a mission objective has to be completed, there is usually more flexibility in how much work or training is done each day during unit deployments compared to the military training school course schedules. If time is allotted to eat, intakes will be higher (Kramer, 1995). However, since field training usually has levels of energy expenditure greater than 16 MJ/day, even with a standard food provision, energy deficits result since only 4–5 MJ per meal times three meals are provided and consumed (Baker-Fulco, 1995). As shown in Fig. 1, energy deficits existed in all field studies. The group that was in energy surplus was a group of support soldiers training in garrison.

In contrast to the above studies of military training schools where students exhibited modest overall energy deficits, students enrolled in the US Army Ranger School Course in the early 1990s had large, sustained energy deficits (note: this is no longer the case) associated with food restriction and an average total energy expenditure of 16.8 MJ/day over the 62-day course (Moore et al., 1992). The energy provided during the initial study of Ranger trainees averaged 11.7 MJ/day resulting in large energy deficits (Moore et al., 1992). Weight loss was severe, 15.6% of initial body weight. Body fat declined from 14.0 to 5.0% of body weight over the course (Moore et al., 1992). A second study during the Ranger School Course was conducted after the food provision was increased

(Shippee et al., 1994). The total energy expenditure measured during this second study was 17.1 MJ/day (Shippee et al., 1994). The estimated energy intake during the second Ranger School Course study increased by 14% over the first study to 13.5 MJ/day, and the Ranger trainees had an 18% lower energy deficit (4.1 MJ/day) (Shippee et al., 1994). Weight loss was still significant in this second Ranger study, with a 12% loss of body weight. Body fat reduction was less severe in the second study, declining from 14.0 to 8.4% of body weight (Shippee et al., 1994). The detrimental levels of body energy store depletion (with 5% body fat the absolute minimum) or unacceptable weight loss (greater than 10%) were shown to produce harmful effects to military personnel's health and job performance (Friedl et al., 1994; Moore et al., 1992; Shippee et al., 1994). Ranger training represents the extreme case in regard to the duration of energy deficits observed during military training. These deficits were produced by purposeful energy restrictions and are not representative of most military deployments. However, they do provide an indication of the importance of providing sufficient energy during long deployments or a rapid succession of deployments to minimize the potential detriments associated with prolonged underfeeding. It should be noted that the extremes noted here do not exist in current Ranger training because of changes made to the course.

In another study with US Army Special Forces, soldiers received either a standard Meal, Ready-to-Eat (16.8 MJ/day available) or the Ration, Lightweight (8.3 MJ/day available) (Askew et al., 1987). Those in the Ration, Lightweight group lost 5.6% of their body weight (4.3 kg) compared to a 1.5% (1.1 kg) body weight loss in the Meal, Ready-to-Eat group (DeLany et al., 1989). Yet, despite less energy provided with the Ration, Lightweight compared to the Meal, Ready-to-Eat, there was no difference in total energy expended. Both groups had the same mission, and therefore the mission dictated the energy expended, not the availability of food energy. This study further illustrates the lack of influence energy intake has on energy expenditure in a non-military school training environment for military personnel with short-term deployments of less than a month. It also demonstrates the tradeoff between providing sufficient energy that the soldier must carry versus carrying a lighter load with insufficient energy. Inadequate food intake among soldiers has been attributed to a number of factors besides the inability to carry a heavy ration. Other factors include: lack of time, poor ration palatability, menu boredom, lack of water, and decreased appetite (Hoyt and Honig, 1996; Kramer, 1995; Kramer, Lesher, & Meisleman, 2001; Popper, Smits, Meiselman, & Hirsch, 1989).

Environmental heat stress

Environmental heat stress did not affect military personnel's energy expenditures. In a study conducted in the desert, Marine artillery crews expended an average of 17.2 MJ/day (Tharion et al., 1997a), similar to the 17.8 MJ/day value obtained during artillery training in the cold (King et al., 1992) (Table 2). Most of the desert artillery training took place during the day when the mean air temperature was 20.6 °C. However, high solar loads during cloudless days and rapid cooling at nights, typical of desert conditions, produced a wide range of temperatures (7–32 °C). Similar total energy expenditures (16.5 MJ/day) were observed in infantry soldiers conducting combat training during the summer in Israel, with temperatures ranging from 23 to 31 °C (Burnstein et al., 1996). In this study, the training took place in mountainous terrain and included load carriage. Total energy

Table 2
Total energy expenditures per day of military men performing similar missions in the cold and heat

Population (reference)	Task	Environment	N	Duration (days)	Total energy expenditure[a] (MJ/day (kcal/day))	Total energy expenditures/kg body mass[a] (MJ · kg^{-1} · day^{-1} (kcal · kg^{-1} · day^{-1}))
US Army soldiers (King et al., 1992)	Artillery field exercise	Cold	10	10	17.8 ± 2.0 (4253)	0.22 (53.8)
US Marines (Tharion et al, 1997a)		Warm	19	12	17.2 ± 3.0 (4115)	0.22 (53.1)
Israeli infantry soldiers (Burnstein et al., 1996)	Infantry combat training	Cold	18	12	17.9 ± 0.7 (4281)	0.25 (60.6)
		Hot	12	12	16.5 ± 0.7 (3937)	0.24 (58.1)
US Marine officers officer training course (Hoyt et al., 2001)	Infantry combat training	Cold	10	10	22.5 ± 2.8 (5378)	0.28 (66.4)
Hoyt unpublished data, reference note 3		Warm	10	7	17.4 ± 2.5 (4156)	0.22 (51.7)

[a] Total energy expenditures in MJ are expressed as mean ± SD and mean (kcal).

expenditures of these Israeli infantry soldiers were 8% less in the summer compared to winter training (17.9 MJ/day). Reasons for the energy expenditure increase in the cold for these infantry soldiers are discussed below in the cold section of this paper. Comparing the energy demands of artillery exercises or infantry training exercises showed that total energy expenditures were similar to, or lower than, values observed in cooler conditions. One reason for this could be that military personnel perform less work in hot environments, but a more plausible explanation is that work is done more efficiently on hot, dry, clear days.

To help support the notion that soldiers work hard in hot environments are the total energy expenditures of Zimbabwean soldiers conducting Commando combat training in African dry field and forest areas with environmental conditions of 40 °C and 29% relative humidity. These soldiers expended 23.0 MJ/day for 12 days, which are the highest rates of energy expenditure of any group measured for over a week. In contrast, their support soldiers only expended 14.0 MJ/day over the same time period in the same hot climate (Mudambo et al., 1997). Total energy expenditures of the Zimbabwean combat soldiers in this hot environment were similar to those recorded by Hoyt et al. (2001) for Marines participating in combat training in a cold environment (Table 2). The total energy expenditures of the support soldiers in Mudambo et al. (1997) study were similar to those recorded for support soldiers operating in a temperate environment (Bovill et al., 2002), further suggesting it is primarily the type of activity that dictates energy expenditure rather than the ambient thermal conditions.

In a jungle environment, Royal Australian Air Force airmen at a base in Northern Australia expended about 15.5 MJ/day during a 12-day ground exercise (Booth, Coad, Forbes-Ewan, Thomson, & Niro, 2001). Activities included movement of supplies and personnel, and defense of the airfield. Temperatures ranged between 24 and 33 °C with a relative humidity of between 71 and 96%. The total energy expenditure of 15.5 MJ/day for Australian combat training in the heat is similar to that of Israeli soldiers (16.5 MJ/day) conducting combat training in the heat. In the Australian study, it rained every day with up to 10 cm of rain falling in 2 h. The somewhat lower total energy expenditure in the Australian study may reflect that some military tasks and physical fitness training was shortened due to environmental conditions, particularly rain, although this was not systematically documented. In contrast, Australian soldiers participating in jungle-warfare combat training expended an average of 19.9 MJ/day (Forbes et al., 1989). The higher total energy expenditures in this study compared to the previous study are again, most likely related to the type of military activities performed. Activities occurring during the Forbes et al. (1989) study included both brief, but intense activities such as bayonet fighting and running of obstacle courses, and prolonged and continuously moderate to hard work activities, such as 10–18 km walks with equipment (e.g. weapon, and backpacks). Slightly higher total energy expenditures were documented in Special Forces students at the Special Forces Assessment School during similar training in a temperate environment. However, while the length of day and activity per hour are not available for the Forbes et al. (1989) study, the difference in total energy expenditures between these two studies is most likely the result of the continuous nature of physical activity and long training days typical at military training school classes previously described in this review, and not the result of environmental differences between combat training in the heat versus a temperate climate.

Data presented in this section suggest a wide range of total energy expenditures can occur while training or working in the heat. Since similar values for military personnel conducting similar training have been observed in temperate, cool, and cold environments, it appears that energy expenditures are primarily related to the type and duration of activities performed not the hot environmental conditions per se. A caveat to this statement is that physical activity is limited necessarily in the heat and, therefore, mission conduct may have been adjusted downward to prevent hyperthermia and dehydration (Glenn et al., 1990; Sawka et al., 1994). Furthermore, none of the studies conducted in extreme environmental conditions (heat, cold, and altitude) were designed as controlled studies to test environment effects; therefore, the conclusions are observational not experimental. A fruitful area for future research may be to determine definitively how energy requirements change when the same mission must be completed in a variety of conditions; temperate, hot, and cold environments with dry or wet climates.

Environmental cold stress

Total energy expenditures during military operations increase in cold environments. Total energy expenditures of 22.6 MJ/day were observed in a study of US Marines participating in a cold-weather Infantry Officer Course (ambient temperature range of −10 to 5 °C) in Quantico, VA (Hoyt et al., 2001). In contrast, total energy expenditures were about 17.4 MJ/day in a similar warm weather (ambient temperature range of 9–31 °C) Infantry Officer Course, i.e. the same course in the same location (Table 2) (Reference Note 3). Activity monitor data suggest the higher level of energy expenditure in the winter course was associated with a longer, more physically demanding workday than during warmer weather exercises. The total loads carried by the two groups of Marines were similar (55 kg).

Examination of total energy expenditures of Israeli foot soldiers conducting infantry training for 12 days, including load carriage, found they expended 17.9 MJ/day during the cold (4–12 °C), rainy, windy season (Burnstein et al., 1996).

Training was similar to that which took place during the summer. However, these soldiers carried approximately 7 kg more in the winter than in the summer (42 versus 35 kg) adding 1.4 MJ/day or 9% to the energy cost (Table 2). In addition, because of rain associated with the winter months, the terrain was muddy, and many of the marches were conducted in windy conditions, increasing the metabolic cost of negotiating the terrain. Finally, during periods when soldiers were relatively inactive, shivering occurred. While resting metabolism is not altered when a person who is properly clothed is exposed to the cold, if clothing is insufficient, shivering can increase metabolic demand by about 1.8 MJ/h (McCarroll, Goldman, & Denniston, 1979).

When working in cold environments, the weight of winter clothing can increase energy demands by 16% over desert clothing and 8% over temperate clothing (McCarroll et al., 1979). Hobbling (restrictive and friction producing) effects of heavy cold-weather, multi-layered clothing, and cold-weather footwear further increases energy requirements by as much as 15% (McCarroll et al., 1979). The location of the weight of clothing or equipment on the body also influences total energy expenditures. For example, during locomotion, wearing heavy boots increases total energy expenditure to a greater extent than carrying the boots in a backpack (Soule & Goldman, 1972).

Three studies were conducted in extreme cold environments, two at Ft Greely, AK and one at Baffin Island, Canada assessing total energy expenditures during military activities (Edwards, Roberts, & Mutter, 1992; Jones, Jacobs, Morris, & Ducharme, 1993a; King et al., 1992). During one of these studies (Ft Greely), temperatures reached a low of −48 °C (Edwards et al., 1992), while temperatures during the other studies averaged −20 °C at Ft Greely (King et al., 1992) and −25 °C at Baffin Island (Jones et al., 1993a). In the first Ft Greely study, total energy expenditure was 17.8 MJ/day for an artillery exercise (King et al., 1992). During this artillery exercise, total energy expenditures were slightly higher than those of Marines (17.2 MJ/day) participating in similar training in a desert environment (Tharion, 1997a) (Table 2). For US infantry soldiers, total energy expenditures averaged 21.6 MJ/day (Edwards et al., 1992; King et al., 1992), while Canadian infantry soldiers expended 18.1 MJ/day (Jones et al., 1993a). These levels of energy expenditure average 20% higher than those seen in hot weather infantry training (Burnstein et al., 1996). While there was not comparable training to compare to in temperate weather, other studies comparing similar training in the heat versus in temperate weather showed no differences between those climatic conditions. Therefore, it is likely that the 20% higher figure would also pertain to a cold weather increase relative to similar training in temperate conditions.

A study of two Norwegian Commandos (Navy Sea, Air, and Land Sailors (SEALS) participating in an 86-day, 2928 km trek across Greenland reported total energy expenditures of 22.3 MJ/day (Frykman et al., 2001a). Even higher total energy expenditures (using the intake-balance method) of 29.7 MJ/day were observed with these same two Norwegian SEALS in a trek across the Arctic Ocean over the North Pole (Frykman, Sharp, Mello, & Kavanagh, 2001b). These values are among the most extreme energy expenditures reported in military personnel over a sustained period of time, and are not representative of routine military field training. However, these studies further illustrate the high levels of energy expenditure that can be achieved by military personnel operating in cold environments because of difficult terrain. Total energy expenditures increase substantially in the ice and snow and when using or carrying specialized winter equipment such as snowshoes or cross-country skis, which can add up to 5 kg in weight to the carried load. Energy expenditures can increase by as much as 30% for locomotion on hard-packed snow and up to 500% for deep snow compared to values measured on a blacktop road (McCarroll et al., 1979).

In summary, the limited data available that allow comparisons between training in the cold and more temperate conditions support the conclusion that training in cold environments increases daily energy requirements. The weight of additional clothing and equipment probably is the most likely reason for the increased energy cost in the cold when snow and ice are not present. Shivering and other non-purposeful movements such as fidgeting also increase energy requirements. Difficult terrain such as snow-covered or icy ground is often present, which also increases energy expenditures. Depending on the depth of the snow, the energy cost of locomotion can increase substantially. Furthermore, because certain activities are more difficult to perform in the winter, biomechanical inefficiencies further increase total energy expenditures in cold environments compared to temperate or hot environments.

High altitude

Energy expenditures of military personnel often increase as the result of working at high altitudes. The effect of hypoxia is the only factor unique to altitude that increases energy expenditures, but other factors that increase energy expenditure such as carrying specialized equipment, rough terrain, and additional clothing are more prevalent at high altitude. US Army construction engineers deployed to Potosi, Bolivia (altitude of 3500–4050 m) had total energy expenditures of 14.8 MJ/day for 10 days while building an airport runway and access road, conducting military readiness training, and providing local humanitarian assistance (Edwards et al., 1991). These values were slightly higher than total energy expenditures of 14.5 MJ/day for Marine construction workers performing similar work at sea level (Tharion et al., 2000a). Two explanations may account for the lack of larger differences.

First, the activities were not exactly the same. The Marines were constructing buildings, and it is possible their work was more strenuous than the US Army soldiers' work of constructing the road and runway since the Marines were not riding on bulldozers and in trucks. The second possibility is if the work at high altitude is completed in flatland areas, smaller increases in total energy expenditure will be observed than if activities must be completed on rugged mountain trails typical of most high altitude military training locations.

In comparing Special Forces' training in a temperate sea-level environment to Special Forces' training at high altitude on Mount Rainier, a more dramatic increase in total energy expenditure of 14.5–17.8 MJ/day was observed. The activities required while training on Mount Rainier certainly contributed to the increase in total energy expenditure. These soldiers carried backpacks weighing 30 kg and ascended 550 m to an elevation of 3100 m. This training and hiking occurred in harsh environmental conditions with high winds and snow. High winds such as those experienced on Mount Rainier (Hoyt et al., 1994) also increase energy cost because headwinds can increase locomotion energy costs proportional to the speed of the wind squared (Davies, 1980; Pugh, 1970).

Hoyt et al. (1991b) assessed total energy expenditures of 23 US Marines in a winter warfare training exercise conducted at an altitude of approximately 2550 m. Total energy expenditure during the first four days was 29.8 MJ/day, the highest assessed in military personnel. The high total energy expenditures seen in Special Forces soldiers training on Mount Rainier (Hoyt et al., 1994) and Marines during winter warfare training (Hoyt et al., 1991b) may be associated with the cold, ice, and snow (high altitude environments are often cold environments). Carrying or wearing specialized equipment necessary in mountainous terrain and carrying additional water also can increase energy requirements. The activities of the Marines training at the winter warfare training center (Hoyt et al., 1991b) were very similar to those of the Norwegian Navy SEALS crossing Greenland who also set up camp, and skied and hiked in rough mountainous terrain. However, the additional 7.3 MJ/day expended by the Marines over those of the Norwegian Navy SEALS was likely attributed to the effects of altitude. In the Greenland study, the peak altitude was only 2000 m, generally regarded by most physiologists as having minimal hypoxic effects, with most of the activity by the SEALS occurring at much lower altitudes, including sea level (Frykman et al., 2001a). Furthermore, in another study with Marines conducting cold weather combat training without the effects of altitude total energy expenditures averaged 22.5 MJ/day (Hoyt et al., 2001). These studies help to demonstrate that military training conducted at high altitudes will add to the energy cost above that already required when military personnel are exposed to the cold and snow at sea level. The energy requirements of the Marines conducting training at 2550 m was approximately 30% greater than other cold weather exercises without the effects of altitude. Part of the reason for the increase in energy cost is that when working at high altitudes, travel on foot often requires traversing rugged, steep, mountainous terrain, increasing the cost of locomotion. However, a physiological explanation also is possible as high altitude exposure increases basal metabolic rate from 7 to 17% for at least the first two to three days of exposure (Butterfield et al., 1992; Hoyt & Honig, 1996; Young & Reeves, 2002). Other physiological reasons for increased energy cost at altitude include an increase in ventilation rate and decreased ability to sleep (Roach, Stepanek, & Hackett, 2002; Young and Reeves, 2002).

Energy expenditures of women in the military

Only a few studies have assessed the energy requirements of military women to determine if they differ from men in the same military occupations (Table 3). Total energy expenditures in women may be less than men because, in general, women have a smaller body size, lower lean body mass, and, historically, their job assignments were less physically demanding. Other possible reasons not reviewed here include menstrual cycle changes including amenorrhea, pregnancy, and lactation (Black et al., 1996; Prentice et al., 1994; Wilmore et al., 1992). In 1993, the combat exclusion rule was lifted for women, which opened a number of job categories for women, some with demanding physical requirements. The highest total energy expenditures observed in women in the military were of female Norwegian Ranger cadets participating in sustained operation (food and sleep deprivation) Ranger training (Hoyt et al., 1996). These female cadets expended 23.4 MJ/day, which is lower than the 27.9 MJ/day expended by male cadets participating in the same training. However, after accounting for body mass, the female cadets expended approximately the same amount of energy ($0.40\ \mathrm{MJ \cdot kg^{-1} \cdot day^{-1}}$) as the male cadets ($0.39\ \mathrm{MJ \cdot kg^{-1} \cdot day^{-1}}$) (Hoyt et al., 1996).

High total energy expenditures in women (19.7 MJ/day) were also observed in Marine recruits during their final 54-h 'Crucible' training exercise of Marine Basic Training. Their total energy expenditure was lower than the 25.5 MJ/day reported for men. After adjusting for body mass, men and women did not differ (Castellani et al., 1998). Total energy expenditures also were assessed during 2 weeks of more conventional Marine Basic Training, with much lower total energy expenditures for both women (9.9 MJ/day) and men (16.9 MJ/day) (Bathalon et al., 2003) than during the Crucible exercise (Castellani et al., 1998). Men expended significantly more energy than women during Marine Basic Training both on an absolute basis and after adjusting for body mass (women $0.17\ \mathrm{MJ \cdot kg^{-1} \cdot day^{-1}}$, men $0.23\ \mathrm{MJ \cdot kg^{-1} \cdot day^{-1}}$) (Bathalon et al., 2003). Differences between energy expenditures

Table 3
Total energy expenditures per day of military women and men with similar jobs

Population (reference)	Task	Gender	N	Duration (days)	Total energy expenditure[a] (MJ/day (kcal))	Total energy expenditures/kg body mass[a] ($MJ \cdot kg^{-1} \cdot day^{-1}$ ($kcal \cdot kg^{-1} \cdot day^{-1}$))
Norwegian Ranger cadets (Hoyt et al., 1996)	Sustained operation during Norwegian Ranger training	Female	4	7	23.4±1.6 (5597)	0.40 (95.7)
		Male	6		27.9±1.8 (6678)	0.39 (93.5)
US Marine recruits basic training (Castellani et al., 1998)	Crucible exercise	Female	20	2.25	19.8±2.6 (4727)	0.34 (82.0)
		Male	29		25.6±4.1 (6129)	0.35 (83.0)
US Marine recruits basic training (Bathalon et al., 2003)	Physical training	Female	20	14	9.9±1.6 (2378)	0.17 (41.1)
		Male	10		16.9±4.0 (4048)	0.23 (56.1)
US Army medical field hospital operation (Baker-Fulco et al., 2002)	Administrative	Female	4	11	9.8±1.6 (2332)	0.16 (38.7)
		Male	1		15.5 (3709)	0.14 (34.3)
US Army medical mass casualty exercise (Baker-Fulco et al., 2002)	Medical support	Female	3	11	11.6±1.3 (2781)	0.18 (44.1)
		Male	2		17.5±1.8 (4171)	0.21 (49.2)
US Army medical mass casualty exercise (Baker-Fulco et al., 2002)	Medical	Female	10	11	12.1±1.0 (2899)	0.20 (47.4)
		Male	6		16.4±3.7 (3925)	0.19 (46.1)
US Navy sailors sea training (Tharion et al., 2002)	Varying activities	Female	16	8	11.6±1.8 (2776)	0.17 (40.9)
		Male	9		14.4±3.6 (3446)	0.18 (43.5)

[a] Total energy expenditures in MJ are expressed as mean±SD and mean (kcal).

in men and women may not be entirely accounted for by gender-related differences in body mass. In another study with US Army medical personnel participating in a mass casualty exercise, total energy expenditures of male soldiers (16.3 MJ/day) were greater than those of female soldiers (11.7 MJ/day) (Baker-Fulco et al., 2002; Tharion, DeLany, & Baker-Fulco, 2001). As in Bathalon et al. (2003) study, total body mass did not totally account for the gender difference (Tharion et al., 2001). However, after controlling for lean body mass, gender differences were no longer observed (Tharion et al., 2001). Since the overall work levels in this study were relatively moderate, basal metabolic rates accounted for a greater proportion of the overall total energy expenditure reflecting the significant gender difference. Since men generally have a greater lean body mass compared to women, their metabolic rates are higher, contributing to a higher total energy expenditure, even on a per kilogram body mass basis (Tharion et al., 2001). While energy expenditure was not reported with lean body mass as a covariate in Bathalon et al. (2003) study, the generally low total energy expenditures in women probably reflect the same phenomenon occurring. In contrast, with high levels of energy expenditure, such as with the Norwegian Ranger cadets, no differences in energy expenditure on a per kilogram body mass basis were seen.

Another reason for a difference in energy expenditures between men and women may be the result of men and women performing different activities, even though they may have the same general military job classification. For example, during a US Army field hospital study (Baker-Fulco et al., 2002), a male laundry shower specialist expended $0.23\ MJ \cdot kg^{-1} \cdot day^{-1}$ while a female radio operator expended $0.17\ MJ \cdot kg^{-1} \cdot day^{-1}$, yet both would be considered combat support activities. This example suggests that when trying to determine the energy requirements of various jobs, specificity of the exact job or military occupational specialty is critical.

Overall, only a limited amount of information is available on the energy requirements of women in the military. It appears that energy requirements of women are typically lower than those of men doing similar activities because women, on average, have a smaller body mass, less lean body mass, and a lower resting/basal metabolic rate than men. Future research to determine the energy needs of women is essential, particularly in women who have physically demanding jobs or long workdays. No research examining energy expenditure in female military personnel controlling for physiological differences such as menstrual cycle, hormone level differences, or compromised nutritional status, has been published.

Practical utility of knowing the total energy expenditures of military personnel

A quantitative understanding of the total energy expenditures of various mission scenarios has practical utility. For example, by being able to estimate total energy expenditures associated with field training, or combat missions, commanders and logisticians can either: (a) plan to minimize energy deficits by providing enough palatable food to meet energy demands; or (b) plan for re-feeding when the military personnel return to garrison or rear areas. This latter situation could be common given that group mean energy intakes from field rations is often less than 12.6 MJ/day (Baker-Fulco, 1995). This data demonstrates

the difficulty of obtaining enough energy in the field to meet occupational requirements. It also emphasizes the importance of re-feeding to allow recovery from deficits that will occur during field deployments.

Knowing the actual energy requirements of military personnel while deployed to the field may also help determine which combination of field rations might help maintain health and ensure optimal performance. It may also help guide ration developers in the development of new improved rations to meet these nutritional requirements under various operational and environmental conditions. Furthermore, by knowing energy costs of various types of garrison activities, commanders may choose to reduce the duration and intensity of training activities in garrison in the interest of achieving the necessary post-deployment re-feeding. If weight losses have been severe, intense training while re-feeding could be counter-productive.

Knowledge of the energy requirements of specific situations could be used to tailor the food provisions to better support the needs of various groups of military personnel (reference notes 1 and 2). Also, knowing energy requirements could provide a quantitative basis for increasing the food budget of physically active military units. Furthermore, total energy expenditure requirements for military personnel's activities are needed to estimate the minimum macronutrient requirements when conditions result in restricted food/ration intake. For example, there are minimal levels of dietary carbohydrate to maintain physical performance, retard losses in lean body mass (Fitts, 1996; Hoyt et al., 1997), and to prevent declines in cognitive performance (Lieberman, Falco, & Slade, 2002). Also, by knowing the total energy requirements of a mission (especially those that are of long duration), and the body fat reserves of their troops, medical personnel may be able to identify individuals at increased health risk because of low body fat energy reserves. The lower body fat limit for healthy men is approximately 5% body weight (Friedl et al., 1994) while for women it is approximately 12% of body weight (McArdle, Katch, Katch, & 1996). Calculation of body composition in the field can easily be accomplished using body circumference measurements (Hodgdon & Friedl, 1999).

Summary

Energy expenditures during military exercises vary primarily as a function of the amount of physical activity being performed. When soldiers are deployed to the field, long workdays can result with daily energy expenditures often exceeding 16.5 MJ/day. Participating in simulated combat training usually results in higher energy expenditures than conducting non-combat activities. Cold and high altitude environments tend to increase energy requirements because military personnel usually carry more weight and engage in more strenuous activities as a result of the footing and terrain. Hot environments do not appear to increase or decrease total energy expenditures. Universally, women have lower total energy expenditures than men, presumably as a result of having less lean body mass, lower resting metabolic rates and being assigned to less physically demanding jobs.

The data presented here illustrate the tremendous range of total daily energy expenditure of military personnel. Military field feeding systems should have the flexibility to provide military personnel with food for up to 20 MJ/day or more if energy balance is to be maintained. Since energy balance often cannot be achieved while in the field, the present data can be used to estimate essential carbohydrate needs, the optimal macronutrient mix, and specific micronutrient requirements needed to maintain health and optimal performance. These data may also be useful in determining the amount of re-feeding required when military personnel return from a physically demanding deployment. Secondly, the data may also help determine the appropriate monetary reimbursement necessary to provide to the food service operations responsible for the re-feeding of these military personnel.

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Appendix. Total energy expenditures by the doubly labeled water method of military personnel in different environments performing various tasks

Population	Task	Gender	Location	Weather[a]	T (°C) ambient[a]	Setting or condition[a]	N	Duration (days)	Total energy expenditure[a] (MJ/day (kcal/day))	Activity[a] (h/day)	Total energy expenditures/kg body mass[a,b] MJ · kg^{-1}·day^{-1} (kcal · kg^{-1}·day^{-1})	Reference
US Army medical field hospital operation	Administrative	Female	Camp McCall, NC	Temperate	NA	Grass field and forest	4	11	9.8 ± 1.6 (2332)	NA	0.16 (38.7)	Baker-Fulco et al. (2002) and Tharion et al. (2001)
US Marine recruits in garrison	Basic training	Female	Parris Island, SC	Hot	NA	Grass and road areas	10	14	9.9 ± 1.3 (2360)	NA	0.18 (43.3)	Bathalon et al. (2003)
US Marine overweight recruits in garrison	Basic training	Female	Parris Island, SC	Hot	NA	Grass and road areas	10	14	10.0 ± 1.9 (2396)	NA	0.16 (38.8)	Bathalon et al. (2003)
US Navy sailors sea training	Varying activities	Female	Aboard ship under sail at sea	Temperate	NA	Indoor on ship	16	8	11.6 ± 1.8 (2776)	NA	0.17 (40.9)	Tharion et al. (2002, 2004c)
US Army medical field hospital operation	Medical support	Female	Camp McCall, NC	Temperate	NA	Grass field and forest	3	11	11.6 ± 1.3 (2781)	NA	0.18 (44.1)	Baker-Fulco et al. (2002) and Tharion et al. (2001)
US Army medical field hospital operation	Medical	Female	Camp McCall, NC	Temperate	NA	Grass field forest	10	11	12.1 ± 1.0 (2899)	NA	0.20 (47.4)	Baker-Fulco et al. (2002) and Tharion et al. (2001)
US Marines construction mission	Administrative and staff work	Male	Bahamas	Warm and sunny	20–33°C	Grass fields and sandy area	6	21	13.0 ± 2.3 (3109)	7.5	NA	Tharion et al. (2000a,b)
Australian sailors shore duty	Maintenance	Male	Australia	NA	NA	NA	11	11	13.8 ± 2.5 (3310)	NA	NA	Forbes-Ewan et al. (1990)
US astronauts flight mission	Flying shuttle and scientific work	Male	Outer space	Temperate	NA	Indoor	4	16	13.9 ± 0.6 (3320)	NA	0.17 (39.9)	Stein et al. (1999)
Zimbabwean soldiers combat training	Support activities	Male	Zambezi valley	Hot and dry	40 °C, 39% RH	African bush	4	12	14.0 ± 1.0 (3346)	8	0.21 (50.4)	Mudambo et al. (1997)
US Army soldiers Special Forces unit	Support activities while in garrison	Male	Ft Carson, CO	Temperate	NA	Forest and mountainous	10	9	14.4 ± 2.9 (3445)	NA	0.20 (47.1)	Bovill et al. (2002) and Tharion et al. (2004a)
US Navy sailors sea training	Varying activities	Male	Aboard ship under sail at sea	Temperate	NA	Indoor on ship	9	8	14.4 ± 3.6 (3446)	NA	0.18 (43.5)	Tharion et al. (2002, 2004c)
US Special Forces combat training	Combat training	Male	Camp Ethan Allen, VT	Temperate	−1 to 16 °C	Forest	8	9	14.5 ± 3.6 (3460)	14.0	0.19 (46.3)	DeLany et al. (1989)

US Marines construction mission	Construction	Male	Bahamas	Warm and sunny	20–33 °C	Grass fields and sandy area	6	21	14.5±3.1 (3460)	7.5	NA	Tharion et al. (2000a,b)
US Army Ranger students	Ranger training swamp phase	Male	Eglin AFB, FL	Hot and wet	32 °C	Jungle and swamp area	5	16	~14.6[c] (3500)	20.75	0.21 (49.3)	Moore et al. (1992)
US Army soldiers construction mission	Build road and airstrip	Male	Boliva	Temperate high altitude	NA	Mountainous	11	10	14.8±2.6 (3549)	NA	NA	Edwards et al. (1991)
US Army soldiers transportation unit	Driving and repairing vehicles	Male	Ft Stewert, GA	Hot and sunny	22–33 °C 49–93% RH	In vehicles or motor pool	3	16	14.9±3.1 (3568)	NA	0.20 (46.7)	Tharion et al. (1998)
US Marines winter combat training	Military training 10 km ski, 10 km biathlon, snowshoeing	Male	Bridgeport, CA	Cold and snow	−15 to 33 °C	2210 m altitude, mountainous	23	7	15.2±1.0 (3632)	NA	0.19 (45.5)	Hoyt et al. (1991b)
Australian airman combat training	Airfield ground defense exercise	Male	RAAF Base Scherger, Australia	Tropical hot and rainy	24–33 °C 71–96% RH	Airfield	8	12	15.5±4.4 (3705)	NA	NA	Booth et al. (2001)
US Army medical field hospital operation	Administrative	Male	Camp McCall, NC	Temperate	NA	Grass field and forest	1	11	15.5 (3709)	NA	0.14 (34.3)	Baker-Fulco et al. (2002) and Tharion et al. (2001)
US Army Ranger students	Ranger training desert phase	Male	Ft Bliss, TX	Hot and dry	29 °C	Desert	5	14	~15.9[c] (~3800)	19.9	0.22 (53.5)	Moore et al. (1992)
US Army medical field hospital operation	Medical	Male	Camp McCall, NC	Temperate	NA	Grass field and forest	6	11	16.4±3.7 (3925)	NA	0.19 (46.1)	Baker-Fulco et al. (2002) and Tharion et al. (2001)
Israeli infantry soldiers combat training	Infantry training load carriage	Male	Northern Israel	Hot and sunny	23–31 °C	Mountainous rough terrain	12	12	16.5±0.7 (3937)	NA	0.24 (58.1)	Burnstein et al. (1996)
US Army Ranger students	Ranger training mountain phase	Male	Camp Darby, GA	Temperate to hot	10–29 °C	Mountainous	5	19	~16.5[c] (~3950)	20.8	NA	Shippee et al. (1994)
US Army Ranger students	Ranger training swamp phase	Male	Eglin AFB, FL	Temperate to hot	9–28 °C 24–98% RH	Jungle and swamp area	6	16	~16.7[c] (~4000)	19.7	NA	Shippee et al. (1994)
US Army Ranger students	Ranger training all phases	Male	Training Sites in GA, FL, TX	Temperate to hot	5–33 °C	Forest, jungle mountain, desert	6	62	16.8±3.5 (4010)	20.4	0.24 (56.5)	Hoyt, Moore, DeLany, Friedl, and Askew (1993) and Moore et al. (1992)

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Population	Task	Gender	Location	Weather[a]	T (°C) ambient[a]	Setting or condition[a]	N	Duration (days)	Total energy expenditure[a] (MJ/day (kcal/day))	Activity[a] (h/day)	Total energy expenditures/kg body mass[a,b] $MJ \cdot kg^{-1} \cdot day^{-1}$ $(kcal \cdot kg^{-1} \cdot day^{-1})$	Reference
US Marine recruits in garrison	Basic training	Male	Parris Island, SC	Hot	NA	Grass and road areas	10	14	16.9±4.0 (4048)	NA	0.23 (56.1)	Bathalon et al. (2003)
US Army Ranger students	Ranger training all phases	Male	Training Sites in GA, FL, TX	Temperate to hot	9–33 °C	Forest, jungle mountain, desert	6	69	17.1±2.0 (4090)	20.4	NA	Shippee et al. (1994)
US Army Special Forces soldiers	Combat training while in garrison	Male	Ft Carson, CO	Temperate	NA	Forest and mountainous	10	9	17.2±3.1 (4099)	NA	0.21 (49.3)	Bovill et al. (2002) and Tharion et al. (2004a)
US Army Ranger students	Ranger training desert phase	Male	Ft Bliss, TX	Hot and dry	17–37 °C 16–84% RH	Desert	4	19	~17.2[c] (~4100)	20.6	NA	Shippee et al. (1994)
US Marines artillery unit	Artillery training exercise	Male	Chocolate Mountain, CA	Temperate to hot, dry	7–32 °C 10–55% RH	Desert	19	12	17.2±3.0 (4115)	12–15	0.22 (53.1)	Tharion et al. (1997a,b, 2004b)
US Marine officer trainees	Combat training during officer training course	Male	Quantico, VA	Warm and sunny	9–31 °C	Field and forest areas	10	7	17.4±2.5 (4156)	16.9	0.22 (51.74)	Hoyt, reference note 3
US Army medical field hospital operation	Medical support	Male	Camp McCall, NC	Temperate	NA	Grass field and forest	2	11	17.5±1.8 (4171)	NA	0.21 (49.2)	Baker-Fulco et al. (2002) and Tharion et al. (2001)
Canadian soldiers arctic training	Infantry training	Male	Canadian Arctic	Cold	−40 to +5 °C, −25 °C avg	Snow and ice	10	9	17.5±4.0 (4179)	NA	NA	Jones, Jacobs, Morris, and Ducharme (1993b)
US Army Ranger students	Ranger training forest phase	Male	Ft Benning, GA	Temperate to hot	29 °C avg	Forest	5	16	~17.6[c] (~4200)	20.3	0.25 (59.2)	Moore et al. (1994)
US Army Ranger students	Ranger training forest phase	Male	Ft Benning, GA	Temperate to hot	19–35 °C 41–100% RH	Forest	4	16	~17.6[c] (~4200)	20.5	NA	Shippee et al. (1994)
US Army Special Forces soldiers	Winter combat training	Male	Mt. Rainer, WA	Cold and snowy, windy	−15 to +5 °C	Mountainous snow, 4392 m altitude	6	6	17.8±2.4 (4248)	16.3	0.23 (54.3)	Hoyt et al. (1991a, 1994)
Israeli infantry soldiers combat training	Routine field maneuvers	Male	NA	Cold	0–12 °C 75–100% RH	NA	19	12	17.8±2.7 (4249)	NA	0.25 (59.0)	Burnstein et al. (1993)
US Army soldiers artillery unit	Artillery training exercise	Male	Ft Greely, AK	Cold	−40 to −6 °C, −20 °C avg	Snow and ice	10	10	17.8±2.0 (4253)	16.6	0.22 (53.8)	King et al. (1992)

Israeli infantry soldiers combat training	Infantry training load carriage	Male	Northern Israel	Cold and rainy	4–12 °C, −16 °C wind chill	Mountainous rough terrain	18	12	17.9±0.7 (4281)	NA	0.25 (60.6)	Burnstein et al. (1996)
Canadian soldiers arctic training	Infantry training	Male	Baffin Island, Canadian Arctic	Snow and ice	−40 to +5 °C, −25 °C avg	Snow and ice	10	10	18.1±3.9 (4317)	8.1	0.24 (56.1)	Jones et al. (1993a)
US Army Rangers in garrison	Physical training	Male	Ft Stewart, GA	Hot and sunny	22–33 °C 49–93% RH	Grass and road areas	8	8	18.9±2.6 (4518)	NA	0.26 (61.3)	Tharion et al. (1998)
US Marine recruits	Basic training crucible exercise	Female	Parris Island, SC	Cool	12.3 °C	NA	20	2.25	19.8±2.6 (4727)	NA	0.34 (82.0)	Castellani et al. (1998)
Australian soldiers land combat battle school	Infantry training: bayonet fighting, obstacle course, 10–18 km walks	Male	Queensland, Australia	Hot and wet	NA	Jungle	4	7	19.9±2.2 (4750)	NA	0.27 (64.4)	Forbes et al. (1989)
US Marines mountain warfare training	Infantry training	Male	Bridgeport, CA	Cold	−15 to 13 °C	Mountainous 2550 m altitude	23	11	20.6±3.8 (4920)	16.55	0.26 (61.6)	Hoyt et al. (1991a) and Hoyt, Tharion, Santee, Matthew, and DeLany (2002)
US Army soldiers winter training	Infantry training	Male	Ft Greely, AK	Cold	−48; to −3 °C	Snow and ice	8	9	21.6[c] (5170)	NA	NA	Edwards et al. (1992) and King et al. (1992)
US Army Special Forces assessment school	Special Forces training	Male	Camp McCall, NC	Temperate	27 °C, 65% RH	Forest	6	20	21.7±1.4 (5182)	NA	NA	Fairbrother et al. (1995)
US Army Rangers field training	Ranger training	Male	Ft Stewart, GA	Hot and sunny	22–33 °C 49–93% RH	Field and forest areas	8	8	21.7±2.8 (5185)	NA	0.29 (70.4)	Tharion et al. (1998)
US Army Ranger students	Ranger training mountain phase	Male	Camp Darby, GA	Temperate	27 °C	Mountainous	5	16	~21.8[c] (~5200)	20.75	0.31 (73.2)	Moore et al. (1994)
Norwegian navy SEALS traverse of Greenland	XC skiing, kayaking, hiking	Male	Greenland	Cold, windy, wet	−15 °C	Ice, water, uneven and mountainous terrain	2	35	22.3±7.6 (5335)	NA	0.24 (58.3)	Frykman et al. (2001)
US Marine officer trainees	Combat training during officer training course	Male	Quantico, VA	Cold	−5 to 10 °C	Field and forest areas	10	10	22.5±2.8 (5378)	18.2	0.28 (66.4)	Hoyt et al. (2001)

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Population	Task	Gender	Location	Weather[a]	T (°C) ambient[a]	Setting or condition[a]	N	Duration (days)	Total energy expenditure[a] (MJ/day (kcal/day))	Activity[a] (h/day)	Total energy expenditures/kg body mass[a,b] $MJ \cdot kg^{-1} \cdot day^{-1}$ ($kcal \cdot kg^{-1} \cdot day^{-1}$)	Reference
Zimbabwean soldiers field exercise	Commando—infantry training	Male	Zambezi valley	Hot and dry	40 °C, 39% RH	African bush	8	12	23.0 ± 4.2 (5497)	8	0.36 (85.4)	Mudambo et al. (1997)
Norwegian Ranger cadets sustained operations	Food and sleep deprived, ranger training	Female	Ostlandet, Norway	Temperate	9–18 °C	Hilly field/forest	4	7	23.4 ± 1.6 (5597)	21–24	0.40 (95.7)	Hoyt et al. (1996)
US Marine recruits	Basic training crucible exercise	Male	Parris Island, SC	Cool	12.3 °C	NA	29	2.25	25.6 ± 4.1 (6129)	NA	0.35 (83.0)	Castellani et al. (1998)
Norwegian Ranger cadets sustained operations	Food and sleep deprived, ranger training	Male	Ostlandet, Norway	Temperate	9–18 °C	Hilly field/forest	6	7	27.9 ± 1.8 (6678)	21–24	0.39 (93.5)	Hoyt et al. (1996)
US Marines mountain warfare training	Ski and snow shoe training, digging in, setting up bivouacs	Male	Bridgeport, CA	Cold	−15–13 °C	Mountainous 2550 m altitude	23	4	29.8 ± 0.9 (7131)	17.93	0.37 (89.4)	Hoyt et al. (1991b)

[a]NA, not available or not measured.
[b]Total energy expenditures in MJ are expressed as mean ± SD and mean (kcal).
[c]Inferred from graph and/or SD not reported in original report.

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2. Department of the Army, Headquarters, United States Army, Special Operations Command, Fort Bragg, NC 28307-5200. Memorandum from Ralph M. Harris, COL, GS, DCS Logistics, FOR: Headquarters, US Army Research Institute of Environmental Medicine, ATTN: MCMR-UE-NBD (Harris R. Lieberman, PhD), Natick MA 01760-5007. 30 August 1999. SUBJECT: Request a nutritional study be conducted of the 10th Special Forces Group to support request for an increase in the Basic Daily Food Allowance.
3. Hoyt, R.W. Unpublished data from summer 1999 Marine Infantry Officer Course.